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**Abstract**

SN1006 [4] and Cas A [1, 9] supernova remnants have been shown convincingly to have a hard X-ray power-law continuum. This continuum is thought to be the synchrotron radiation from accelerated electrons of  $\sim 100$  TeV at the shock fronts. Our goal of AO2 RXTE observation is to detect the hard X-ray continuum and to determine the nature of the continuum from Tycho SNR. A detection of a power-law continuum from Tycho SNR can strongly argue for SNRs are the source of cosmic rays with the first order Fermi acceleration as the energizing process.

We report the results of our AO2 RXTE  $1 \times 10^5$  sec observation of Tycho SNR. We detect two components of the X-ray spectrum from Tycho SNR both at better than  $3\sigma$  confidence. The best two component models are: bremsstrahlung ( $kT=2.67 \pm 0.13$  keV) + bremsstrahlung ( $kT=7.07 \pm_{1.72}^{2.21}$  keV) or bremsstrahlung ( $kT=2.36 \pm_{0.57}^{0.21}$  keV) + power-law ( $\Gamma=2.58 \pm_{0.09}^{0.12}$ ). This result is an improvement compared with the previous most sensitive X-ray measurements by Ginga which shows Tycho's observed X-ray continuum requires a two-component model to yield acceptable fits with the hard component parameters being highly uncertain. Our RXTE measurements constrain all parameter within  $3\sigma$  ranges. However, we cannot yet distinguish between thermal and nonthermal models for the hard component. In the followings, we describe what we accomplished in the period covered by the grant proposal.

## Observation

Tycho SNR observation was performed by the RXTE satellite on Feb 2 - Feb 6, 1997 and was designated as RXTE observation #20255. We received the production data in a 4mm DAT tape from the RXTE GOF on July 28, 1997. In order to analyze the RXTE data, we installed *ftools* software in our workstations. *ftools* was obtained from [http://heasarc.gsfc.nasa.gov/docs/software/ftools/ftools\\_menu.html](http://heasarc.gsfc.nasa.gov/docs/software/ftools/ftools_menu.html) and is written by scientists at NASA/GSFC. Co-PI, Dr. Phil Blanco at UCSD did the data screening and produced the background subtracted spectrum of the HEXTE data (15 - 100 keV). PI, Dr. Lih-Sin The at Clemson University did the data screening of the PCA data (2 - 30 keV) and then analyze the combined PCA and HEXTE data to determine the best fit spectrum of Tycho SNR. In performing the data screening and analysis processes, we inquired some technical questions to the RXTE GOF and we received many beneficial helps from the competent and nice people at the RXTE GOF (Drs. Alan Smale and Arnold Rots).

## Results

RXTE  $1 \times 10^5$  sec observation of Tycho SNR produces clean  $8.96 \times 10^4$  sec of PCA data and  $6.22 \times 10^4$  sec of HEXTE data. In Table 1, we summarize the result of best fitting PCA and HEXTE data and in Figure 1 we show the count and photon spectrum of the data and the bremsstrahlung + power law best fit model. In the fit we fix the hydrogen column density to  $2.5 \times 10^{21} \text{ cm}^{-2}$ . Models with a single component are rejected with a very high confidence. The PCA and HEXTE required two component model to give acceptable fit. However, fittings of the data cannot differentiate the bremsstrahlung + bremsstrahlung model from the bremsstrahlung + power law model. The parameters of the models in Table 1 are in good agreement with the fit spectra of Ginga data. *Note that while Ginga's hard X-ray parameters are highly uncertain [3], our RXTE observation constrains the parameters much better with each component of the continuum flux being detected at better than  $3\sigma$  confidence.* We [10] find the X-ray spectrum from RXTE measurement is consistent with the results from Ginga [3] and HEAO-1/A2 [5] measurements. Interesting enough, the power-law index of Tycho's hard X-ray component of  $\sim 2.6$  has a similar value compared with the power-law index of SN1006 (2.95), Cas A (2.98), RX J1713.7-3946 (2.45), and IC443 (2.35).

Table 1: Tycho's SNR X-ray Spectrum from RXTE Observation

Model <sup>a</sup>	1st Component <sup>b</sup>	2nd Component <sup>b</sup>	$\chi^2/\text{dof}$
bremss + bremss	kT=2.67±0.13 f=(5.49± <sup>0.23</sup> <sub>0.19</sub> )×10 <sup>-2</sup>	kT=17.07± <sup>2.21</sup> <sub>1.72</sub> f=(8.24± <sup>0.87</sup> <sub>0.81</sub> )×10 <sup>-3</sup>	496.8/95
bremss + power law	kT=2.36± <sup>0.21</sup> <sub>0.57</sub> f=(2.17± <sup>0.52</sup> <sub>0.77</sub> )×10 <sup>-2</sup>	Γ=2.58± <sup>0.12</sup> <sub>0.09</sub> f=(7.64± <sup>2.91</sup> <sub>1.69</sub> )×10 <sup>-2</sup>	494.8/95

<sup>a</sup> The total hydrogen column density towards Tycho is fixed to a value of  $2.5 \times 10^{21} \text{ cm}^{-2}$ .

<sup>b</sup> kT is in units of keV and f is in units of  $\gamma \text{ cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$ .

### Conclusions, Publications, and Future Work

During the period covered by the grant, we also analyzed the RXTE/PCA TOO Cas A observation. We simultaneously fit the 2 - 30 keV RXTE/PCA data with the 40 - 200 keV data we obtained from CGRO/OSSE Cas A SNR observation [8]. The combined data can rule out the single thermal bremsstrahlung model for Cas A continuum between 2 and 150 keV. We also find that a two component bremsstrahlung + power-law model gives a good fit with the power-law index of the hard component being  $(2.98 \pm 0.09)$ , in well agreement with the result of AO1 RXTE (PCA and HEXTE) Cas A observation [1]. The power-law index is strongly constrained allowing us to conclude that the hard power-law continuum cannot be the X-ray thermal bremsstrahlung from accelerated MeV electrons at shock fronts [2] which would have  $\Gamma \simeq 2.26$ . We presented and published the results in the Proc. of the Fourth Compton Symposium [9]. With this results, currently we have two strong evidences of nonthermal power-law continuum with the first evidence is the detection from SN1006 discovered by [4] and the second one is the detection from the combined RXTE and CGRO Cas A observations [1, 9]. If further evidences of nonthermal emission such as from Tycho SNR and other SNRs can be shown convincingly, we can strongly argue that SNRs are the source of cosmic rays.

The most favored model for the power-law X-ray emission is the synchrotron process from electrons that have been energized to  $\sim 100 \text{ TeV}$  within the shock from [6]. Our analysis [9, 10] based on this model and the best estimated magnetic field in Tycho SNR (1 mG, [7]) finds that the energy cutoff of the synchrotron photon is  $\sim 40 \text{ keV}$ . This cutoff energy would appear as an exponential cutoff to the power-law spectrum. We

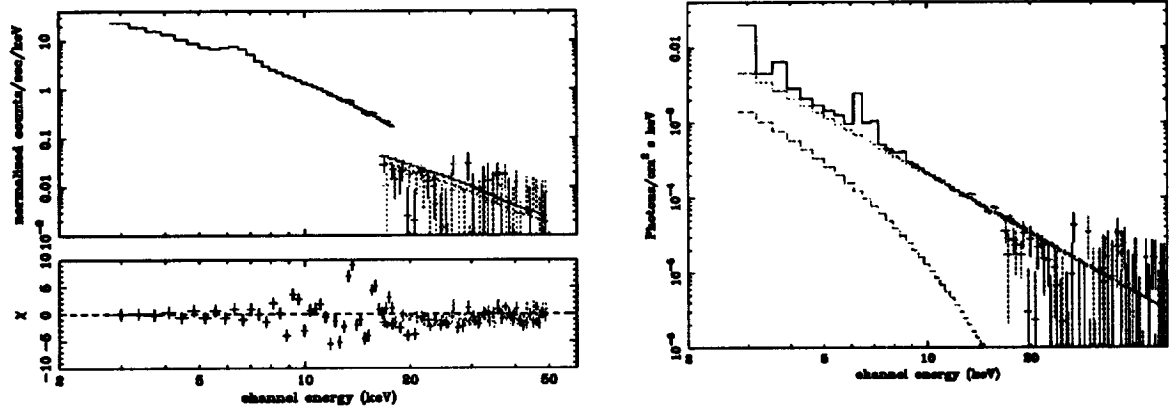


Figure 1: *Tycho SNR X-ray Spectra.* The left panel shows the count spectra of the data and the thermal bremsstrahlung + power-law model with its residuals. The right panel shows the corresponding photon spectra and each of the bremsstrahlung and power law component.

can use this important limit as the test for the viability of the synchrotron model; for example if the power-law spectrum is detected upto i.e. 100 keV, then the synchrotron model becomes questionable.

After the analysis of our AO2 RXTE Tycho SNR data, we realize that the observation was not deep enough to be able to differentiate between a bremsstrahlung model from a power-law model for the hard component. We proposed for a further observation in the AO3 RXTE (proposal #30207), however due to fierce competition for observing time the proposal was not recommended for inclusion in the cycle 3 observing program. Currently we have a CGRO/OSSE Cycle 8 proposal of Tycho SNR observation (proposal CGRO-98-033) under evaluation. In there, we propose to use CGRO/OSSE to observe Tycho SNR for 7 week to detect the 50-100 keV continuum. A detection can definitely decide the nature of the hard continuum and the viability of synchrotron model. We also plan to propose an RXTE Tycho SNR observation in RXTE cycle 4.

Currently, we have been preparing a manuscript reporting our RXTE Tycho SNR observation to the astrophysics community. It will be sent to either the *Astrophysical Journal* or the *Astronomy and Astrophysics Journal*.

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